TRL-1

COLLISION PROBABILITY OF SPACE OBJECTS

Sarthak Kumar, Advisor: Sanat K Biswas
Indraprastha Institute of Information Technology

ABSTRACT

This research delves into algorithms for estimating collision probability among Resident Space Objects (RSOs). The primary goal was to compare the accuracy and computational cost of state-of-the-art algorithms. The focus was on analyzing Patera's and Alfano's methods, using Monte Carlo as a benchmark. The study reveals that while Alfano's method is faster than Patera's, it tends to be less accurate for close approaches. Conclusions drawn include a comparative analysis of the computational expense and efficiency of Patera's and Alfano's methods, indicating that Alfano's method is less computationally expensive but less efficient.

PREFACE

The collision probability computation of space objects plays an important role in space situational awareness, particularly for conjunction assessment and collision avoidance.

PREFACE

Early works mainly relied on Monte Carlo simulations to predict collision probabilities. Although such simulations are accurate when a large number of samples are used, these methods are perceived as computationally intensive, which limits their application in practice. Many approximation methods have been developed over the past three decades to overcome this limitation. Therefore, this study is centred on the analysis of algorithms that prioritize computational efficiency without compromising much on accuracy.

METHODOLOGY

Two state-of-the-art, widely used algorithms were implemented to analyse their accuracy. Two satellites were initialized on two distinct orbits. To calculate their collision probability, they were projected to their closest approach time and then onto a 2-D encounter plane for faster computation. The projected miss vector, relative velocity vector and their standard

METHODOLGY

Deviation in position were then used to compute their collision probability using Patera's and Alfano's methods. The original state of the satellite was used to calculate the collision probability using Monte Carlo simulation and was used as a benchmark for the two algorithms. Different scenarios were generated to compare both algorithms by varying their position vectors.

COLLISION PROBABILITY

The general collision probability calculation is done using trivariate integration over the intersection volume of the 3-D error covariance ellipses related to each RSO.

The method is computationally expensive. Therefore, many algorithms are created to estimate the collision probability faster without losing much efficiency.

Two such algorithms are Patera's Method and Alfano's method.

PATERA'S METHOD

Patera's method reduces the two-dimensional area integral to the one-dimensional line integral over the hard-body circle to an integration about a contour enclosing the area. This is achieved by performing a coordinate rotation and a scale change to make the density distribution symmetric and elliptical.

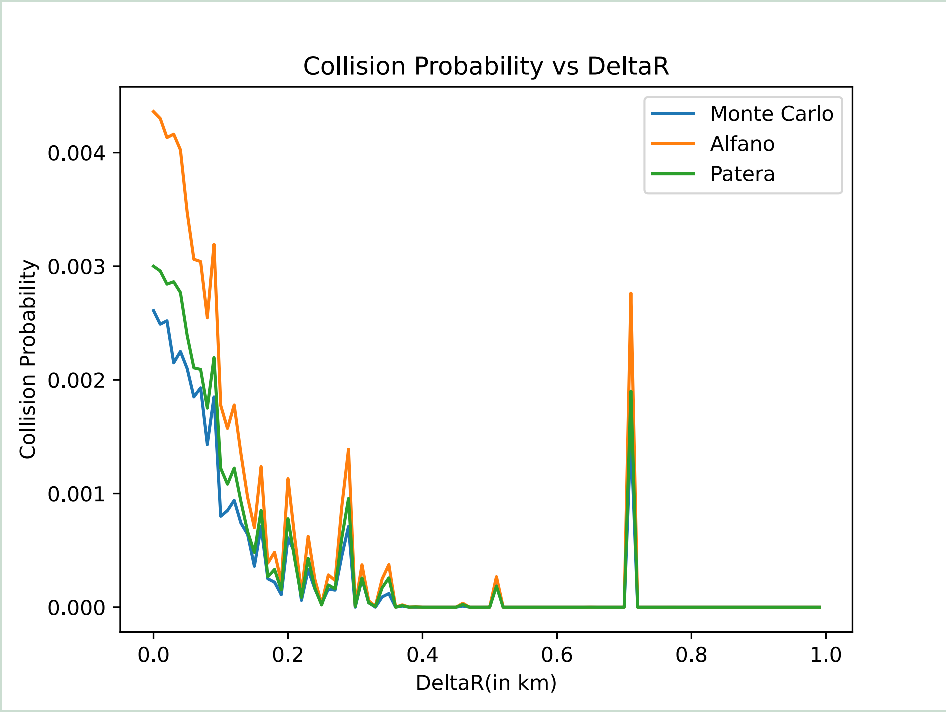
The symmetric form of the probability density enables the two-dimensional integral to be reduced to a one-dimensional integral

ALFANO'S METHOD

Alfano's method utilizes error functions to reduce the two-dimensional integral to a one-dimensional integral. The integral is calculated utilizing the Simpson's one-third rule further improving the computational speed.
A numerical series approximation was presented that computes the collision probability of spherical objects.

$$P = \frac{dx}{3\sqrt{8\pi\sigma x}}(m\_0 + m\_even + m\_odd)$$

CONCLUSION



Both algorithms demonstrate close estimation of collision probability. However, it was noted that Alfano's method, while exhibiting higher computational efficiency, tends to overestimate the collision probability for close approaches.

$$\mathrm{r}_{\text{primary}} = [x, y, z]$$
$$\mathrm{r}_{\text{secondary}} = [x + \delta R, y + \delta R, z + \delta R]$$